Normal-incidence multilayer mirrors for the 8-12 nm wavelength region

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INTRODUCTION

High-resolution normal-incidence diffraction gratings with reflective multilayer coatings are needed for the study of extreme ultraviolet (EUV) spectra from a variety of astrophysical sources. To date, the highest reflectances (~70%) were achieved with Mo/Be and Mo/Si multilayers for wavelength slightly above 11.1 nm (Be L-edge) and 12.4 nm (Si L-edge), respectively.[1] It is of interest to develop similar high reflectance multilayer mirrors with new material pairs for shorter wavelengths, where Mo/Be and Mo/Si multilayers do not work. The Mo/Y and Mo/Sr material pairs have been identified as good candidates for the 8-12 nm wavelength region with potential of producing normal-incidence reflectance above 40%.[2] The fabrication and characterization of Mo/Y and Mo/Sr multilayers with our deposition-reflectometer system is described in this manuscript.

EXPERIMENTAL CONDITIONS

Mo/Y and Mo/Sr multilayer mirrors were fabricated using a magnetron sputtering deposition system[2] and were characterized *in situ* using synchrotron radiation from the ALS beamline 6.3.2. The base pressure in the experimental system is typically in the low 10^{-9} Torr before deposition, and ultra high purity Ar (99.999%) is maintained at a pressure of 2.0 mTorr during deposition. The multilayers were deposited onto small pieces of Si wafers inserted in the chamber with a loadlock assembly, and held at the distance of 19.5 cm from the sources at the center of the chamber. The magnetron sources were operated at a DC power of 50 W for both Mo and Y, and of 30 W for Sr. A multilayer is deposited by alternatively rotating the substrate in front of each deposition source and opening the associated shutter for a predetermined time. Once the deposition completed, the reflectance of the multilayer sample is measured in the *p*-polarized plane at near-normal incidence, i.e., 3.6˚, 5˚, and 7.0˚ from normal-incidence. The long-term stability of some samples was monitored by repeating the reflectance measurements after exposure of the samples to air for given periods of time. Those subsequent measurements were performed using the main CXRO reflectometer permanently bolted to beamline 6.3.2.[3]

EXPERIMENTAL RESULTS

Mo/Y and Mo/Sr multilayer mirrors were investigated in this study. Both types of multilayer have very similar reflectance properties, in theory, and perform best in the 8–12 nm wavelength region.

A. Mo/Y multilayer mirrors

Figure 1 shows the reflectance curves of three Mo/Y multilayer samples measured *ex situ* at 5˚ from normal-incidence (solid curves). Also plotted is the theoretical maximum reflectance Mo/Y multilayers can achieve assuming optimum layer thicknesses at each wavelength, ideal interfaces and infinite number of layers (dotted curve). The multilayer reflecting at shorter wavelength consists of only 50 bilayers while the other two have 100 bilayers. The smaller number of bilayer contributes to the lower reflectance and the larger bandwidth of this sample. Peak reflectances of 20.2%, 33.6% and 46.6% were measured at 8.8 nm, 9.4 nm and 11.5 nm, respectively. These reflectances are slightly higher than those reported in the past[2] and about 70-75% of theoretical maximum for each design wavelength. The discrepancy between the measured and theoretical reflectance is mainly due to interface roughness, layer contamination and surface oxidation.

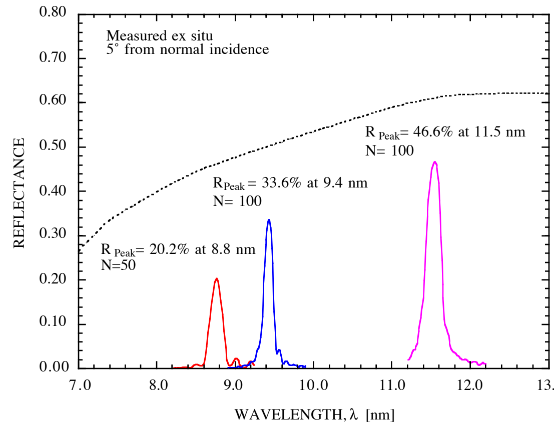

Fig. 1. Near-normal incidence (5˚) reflectance for three Mo/Y multilayer mirrors plotted as a function of wavelength (solid curves), along with the maximum achievable reflectance for each wavelength (dotted curve).

The reflectance stability of several Mo/Y multilayer samples was monitored over a period of fourteen months. After a slight drop of ~1% in reflectance and a peak shift of ~0.1 nm toward shorter wavelengths in the first three months, both the peak reflectance and peak position remained stable.

B. Mo/Sr multilayer mirrors

Mo/Sr multilayers have never been fabricated before, mainly because of the extreme reactivity of Sr with water vapor and oxygen. Our experimental system allows us to deposit multilayers in a UHV environment and then measure their reflectance before exposure to air. Figure 2 shows the reflectance curves of three representative Mo/Sr multilayer samples measured *in situ* at 3.6˚ from normal-incidence (solid curves), along with the maximum achievable reflectance curve (dotted curve). Again, the multilayer at shorter wavelength consists of only 50 bilayers, while the others have 120 bilayers. Peak reflectances of 23.0%, 40.8% and 48.3% were measured at 8.8 nm, 9.4 nm and 10.5 nm, respectively.[4] The reflectance of these Mo/Sr multilayers is about 15-20% higher than the reflectance of the Mo/Y multilayers, but is only 65-70% of the theoretical maximum for each design wavelength.

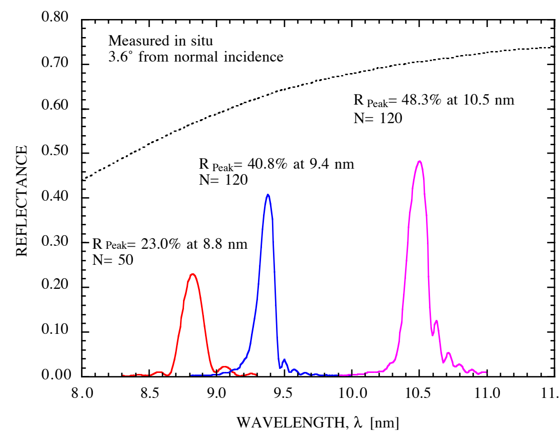

Fig. 2. Near-normal incidence (3.6˚) reflectance for three Mo/Sr multilayer mirrors plotted as a function of wavelength (solid curves), along with the maximum achievable reflectance for each wavelength (dotted curve). The reflectance measurements were made *in situ*, before exposing the samples to air.

However, as a result of the reactivity of Sr with oxygen and water vapor, the reflectance of these Mo/Sr multilayers decayed rapidly after exposure to ambient air. Indeed, while the reflectance of witness samples kept in vacuum or in nitrogen remained stable, the reflectance of samples exposed to air for about 24 hours dropped to less than a percent.[4]

Attempts to use thin layers of C to passivate the surface of these Mo/Sr multilayers were unsuccessful.[4]

CONCLUSION

Mo/Y multilayers provided slightly higher reflectances than reported in the past. They were relatively stable in air at room temperature, however the thermal stability of these Mo/Y multilayers has not yet been investigated. Mo/Sr multilayers were successfully fabricated and gave very encouraging results. The reflectances achieved were better than those obtained with Mo/Y, but the multilayers were not stable due to oxidation. Future studies will focus on the development of capping materials capable to passivate the multilayer surface and therefore preserve their reflectance.

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